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(54) Title: METHOD FOR DERIVING NOISE-REDUCED ESTIMATES OF COLOUR SIGNAL PARAMETERS FROM MULTIPLE COLOUR/LUMINANCE IMAGE SENSOR OUTPUTS
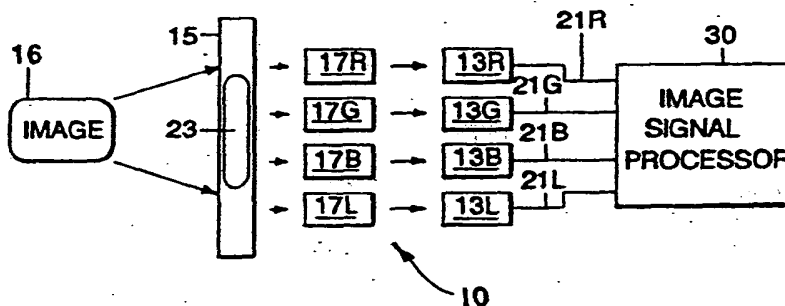
(57) Abstract

Color and luminance measurement signals produced by the multiple sensors of a multiband (e.g. RGB color) image signal processing system are processed to reduce noise. For images such as those obtained from a multi-dye film, the luminance component of the output signal from the luminance sensor may be expressed as a function of the color components of the color sensor output signals. A first signal, representative of the constructed low frequency luminance signal, is produced as a linear function of the color sensor output signals, employing signal weighting coefficients derivable from intrinsic characteristics of the scanned image, such as the respective dye densities of a three layer color film. The luminance measurement signal derived from the luminance sensor is subtracted from this first signal, to produce a second signal, which is multiplied by a set f respective scaling factors, which are then subtracted from each color sensor output, so as to derive a set of noise-reduced estimates of the color components of each of the color sensor output signals. Each scaling factor is defined in accordance with the noise variances associated with the operation of the color image sensors and the luminance image sensor, and is proportional to a product of a corresponding one of the coefficients and the ratio of the noise variance associated with the operation of a respective color image sensor to a summation of the noise variances associated with the operation of each of the color sensors and the luminance sensor.

METHOD FOR DERIVING NOISE-REDUCED ESTIMATES OF COLOUR SIGNAL PARAMETERS

FROM MULTIPLE COLOUR/LUMINANCE IMAGE SENSOR OUTPUTS

5   FIELD OF THE INVENTION

The present invention relates in general to color imagery signal processing and is particularly directed to a mechanism for deriving noise-reduced color signal estimates from a multiple sensor color
10   imaging system.

BACKGROUND OF THE INVENTION

Multi-channel signal processing systems often contain a larger number of sensors than there are bands
15   of information to be extracted. Namely, they may be characterized as containing n sensors for deriving m bands of information, where n>m. For example, a color imagery sensing system, such as employed for high definition television, may, on occasion, contain four
20   image sensors, three of which provide relatively low spatial resolution measurements of the red, green and blue components of an image, such as the red (R), green (G) and blue (B) density of a color film, while the fourth sensor provides a relatively high spatial
25   resolution, luminance-representative (L) output signal. A low spatial frequency luminance signal is generated by resampling the original high resolution luminance signal, so as to replicate the resolution at which the red, green and blue signals are measured. Subtracting
30   this low frequency luminance from the original luminance signal yields only its high frequency component. (Aside from this subtraction step, the low frequency luminance information is not used.) The resulting high frequency component is then added to the
35   red, green and blue signals to produce high frequency information for these channels.

above-referenced three layer film, the luminance
component of the output signal from the luminance
sensor may be expressed as a function of the color
components of the color sensor output signals. Namely,

5   the luminance sensor output L may be expressed as the
sum of a function $f(r,g,b)$ and the luminance sensor
noise n_L, where r, g and b are the color components
within the color sensor outputs for which reduced-noise
estimates are desired.

10   The signal processing mechanism according to
the present invention processes a vector c_i of inputs
(intrinsic parameters) and a vector c_o of measurable
outputs, related by a function $\vec{c}_o = F(\vec{c}_i)$ which may, in
some cases, be approximated by a matrix $\vec{c}_o = A\vec{c}_i$. For

15   a four sensor color imagery processing system, sensor
outputs are processed to reduce the noise components in
the color sensor output signals and thereby derives
noise-reduced estimates of each of the color components
within these sensor output signals. To this end, a

20   first signal, S1, which is representative of the low
frequency luminance signal, is produced as a linear
function of the color sensor output signals, in the
form S1 = (AR + BG + CB), where A, B and C are signal
weighting coefficients derivable from intrinsic

25   characteristics of the scanned image, such as the
respective dye densities of a three layer color film.
The luminance measurement signal derived from the
luminance sensor is subtracted from this first signal
S1, to produce a second signal S2. This second signal

30   S2 is then multiplied by a set of respective scaling
factors, which are then subtracted from each color
sensor output, so as to derive a set of noise-reduced
estimates of the color components of each of the color
sensor output signals. Each scaling factor is defined

35   in accordance with the noise variances associated with
the operation of the color image sensors and the

environment that employs a first plurality of n
measurements on a second plurality of m intrinsic
variables. Specifically, for purposes of the present
description, the environment is that of a multi-color
5   image processing system which carries out n=4
measurements on m=3 intrinsic variables and comprises a
(multiple sensor) color image section 10, containing
red, green, blue and luminance sensitive sensors 13R,
13G, 13B and 13L arranged on one side of a three layer
10   color film strip 15, that is illuminated by light
source 16 having a spectral light intensity $I(\lambda)$.
Situated in front of the sensors are respective input
filters 17R, 17G, 17B and 17L, having respective
transmittances $T_r(\lambda)$, $T_g(\lambda)$, $T_b(\lambda)$ and $T_L(\lambda)$. Each
15   sensor produces image characteristic-representative
digital signals, i.e. respective red, green, blue and
luminance channel signal values representative of the
red, green, blue and luminance components of a color
image 23 captured on film strip 15 which are coupled
20   over links 21R, 21G, 21B and 21L to a processor 30.
         As pointed out above, in the course of
operation of such a multi-channel (e.g. three color
band, luminance band) image scanning system, the color
channel sensors 13R, 13G, 13B provide relatively low
25   spatial resolution measurements of respective red R,
green G and blue B components of the film, such as its
red, green and blue densities, while the fourth,
luminance, sensor 13L provides a relatively high
spatial resolution luminance representative output
30   signal. A low spatial frequency luminance signal is
generated by resampling the original high resolution
luminance signal, so as to replicate the resolution at
which the red, green and blue signals are measured.
Subtracting this low frequency luminance from the
35   original luminance signal yields only its high
frequency component. The resulting high frequency

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processing mechanism of the present invention, it is
useful to initially define the signal outputs of each
of sensors 13 of scanning system 10. Specifically, for
an arbitrary pixel within each sensor, R, G and B

5   denote the signals measured by the red, green and blue
sensors 13R, 13G and 13B, respectively, and L denotes
the low frequency luminance signal (for the same pixel
location) for the measured luminance signal. The
signal values R, G, B and L may be defined as:

10

$$R = r + n_r, \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)$$
$$G = g + n_g, \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)$$
$$B = b + n_b, \text{ and } \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3)$$
$$L = f(r,g,b) + n_L \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

15

(Note that this model set of definitions is appropriate
for scanning a three-layer film,, but not for looking
at real-world scenes.) Here each noise value n_i is an
independent observation noise which is normally

20   distributed with zero mean and variance σ^2_i (σ^2_L is the
effective noise variance of the noise in the low-
frequency luminance signal). The r, g, and b
parameters are the "true" or noise-free red, green and
blue transmittances. The function f is the

25   (deterministic) relationship between the red, green and
blue transmittances and the (low-frequency) luminance
transmittance. An implicit expression for the function
f may be obtained by considering the details of the
scanning process.

30   The scanner uses a light source 16 (with
spectral intensity $I(\lambda)$ shining through film 15
containing three color layers with dye densities d_1, d_2
and d_3. The optical densities of these dyes, as a
function of wavelength, are $D_1(\lambda)$, $D_2(\lambda)$ and $D_3(\lambda)$.

35   Finally, sensors 13R, 13G, 13B and 13L look at the

$$\acute{r} = R - (\sigma^2_r / \sigma^2_L)(f(\hat{r}, \hat{g}, \hat{b}) - L) . \quad df/dr(\hat{r}, \hat{g}, \hat{b}), \quad . \ . \ . \quad (10)$$

$$\hat{g} = G - (\sigma^2_g / \sigma^2_L)(f(\hat{r}, \hat{g}, \hat{b}) - L) . \quad df/dg(\hat{r}, \hat{g}, \hat{b}), \ \text{and} \quad . \quad (11)$$

5

$$\hat{b} = B - (\sigma^2_b / \sigma^2_L)(f(\acute{r}, \hat{g}, \acute{b}) - L) . \quad df/db(\acute{r}, \hat{g}, \hat{b}), \quad . \ . \ . \quad (12)$$

For a general function f, equations (10),
(11) and (12) will be non-linear and will not have a

10 closed form solution. If the function f is linear in
its arguments, however, its solution can be obtained.
Thus, if it is assumed that:

$$f(r,g,b) = \alpha r + \beta g + \gamma b \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (13)$$

15

Then, equations (10), (11) and (12), respectively,
become:

$$\hat{r} = R - (\alpha\hat{r} + \beta\hat{g} + \gamma\hat{b} - L)\alpha(\sigma^2_r / \sigma^2_L) \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (14)$$

20

$$\hat{g} = G - (\alpha\acute{r} + \beta\acute{g} + \gamma\acute{b} - L)\beta(\sigma^2_g / \sigma^2_L) \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (15)$$

$$\acute{b} = B - (\alpha\acute{r} + \beta\acute{g} + \gamma\acute{b} - L)\gamma(\sigma^2_b / \sigma^2_L) \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (16)$$

25 for which the solution is:

$$\hat{r} = R - (\alpha R + \beta G + \gamma B - L)\alpha(\sigma^2_r / \sigma^2_T) \quad . \ . \ . \ . \ . \ . \ . \ . \quad (17)$$

$$\hat{g} = G - (\alpha R + \beta G + \gamma B - L)\beta(\sigma^2_g / \sigma^2_T) \quad . \ . \ . \ . \ . \ . \ . \ . \quad (18)$$

$$\hat{b} = B - (\alpha R + \beta G + \gamma B - L)\gamma(\sigma^2_b / \sigma^2_T) \quad . \ . \ . \ . \ . \ . \ . \ . \quad (19)$$

30

where:

$$\sigma^2_T = \sigma^2_L + \alpha^2\sigma^2_r + \beta^2\sigma^2_g + \gamma^2\sigma^2_b \quad . \ . \ . \ . \ . \ . \ . \ . \quad (20)$$

then the rms error of the estimate becomes (after algebraic simplification):

$$\sigma^2{}_M = \sigma^2{}_M - (\alpha q\sigma^2{}_r + \beta s\sigma^2{}_g + \gamma t\sigma^2{}_b)^2/\sigma^2{}_T \quad \ldots \ldots \ldots \quad (25)$$

5

which is always the better estimate.

In accordance with a preferred embodiment, the system will not be light-limited, so that the noise level from each sensor will be the same. The low-frequency luminance signal is obtained by averaging four luminance measurements, so that its rms noise is half that of the other channels ($\sigma_r = \sigma_g = \sigma_b = 2\sigma_L$). For exemplary parameters $\alpha = .3$, $\beta = .6$, and $\gamma = .1$, equations (17), (18) and (19) yield:

10

15

$$\hat{r} = R - .42A \text{ with } \sigma_{\hat{r}} = (.93)\sigma_r, \quad \ldots \ldots \ldots \ldots \quad (26)$$

$$\hat{g} = G - .85A \text{ with } \sigma_{\hat{g}} = (.70)\sigma_g, \text{ and } \quad \ldots \ldots \ldots \quad (27)$$

20

$$\hat{b} = B - .14A \text{ with } \sigma_{\hat{b}} = (.99)\sigma_b, \quad \ldots \ldots \ldots \ldots \quad (28)$$

where:

$$A = .3R + .6G + .1B = L \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (29)$$

25

By slightly modifying the coefficients to: $\alpha = .4$, $\beta = .5$, and $\gamma = .1$ the values of $\hat{r}$, $\hat{g}$ and $\hat{b}$ become:

$$\hat{r} = R - .60A \text{ with } \sigma_{\hat{r}} = (.87)\sigma_r, \quad \ldots \ldots \ldots \ldots \quad (30)$$

30

$$\hat{g} = G - .75A \text{ with } \sigma_{\hat{g}} = (.79)\sigma_g, \text{ and } \quad \ldots \ldots \ldots \quad (31)$$

$$\hat{b} = B - .15A \text{ with } \sigma_{\hat{b}} = (.99)\sigma_b, \quad \ldots \ldots \ldots \ldots \quad (32)$$

measurement noise. If the film noise (k_r, k_g, k_b) is additive in intensity space, then the measurements may be defined as:

5       $R = r + k_r + n_r,$ . . . . (34)

        $G = g + k_g + n_g,$ . . . . (35)

        $B = b + k_b + n_b,$ and . . . . (36)

        $L = \alpha(r+k_r) + \beta(g+k_g) + \gamma(b+k_b) + n_L$ . . . . (37)

10   If the film noise is additive in density space, the definitions are:

        $R = r10^{kr} + n_r,$ . . . . (38)

        $G = g10^{kg} + n_g,$ . . . . (39)

15      $B = b10^{kb} + n_b,$ and . . . . (40)

        $L = \alpha(r10^{kr}) + \beta(g10^{kg}) + \gamma(b10^{kb}) + n_L$ . . . . (41)

In both cases the maximum likelihood estimators are unchanged from the simpler case discussed previously.
20   Consequently, for the additive in intensity space case, the expression for $\hat{r}$ becomes:

        $\hat{r} = R-(\alpha R+\beta G+\gamma B-L)\alpha(\sigma^2_r/\sigma^2_T)$ . . . . (42)

        $= r+k_r+n_r-(\alpha n_r+\beta n_g+\gamma n_b-n_L)\alpha(\sigma^2_r/\sigma^2_T)$ . . . . . . (43)

25

Similar expressions may be derived for $\hat{g}$ and $\hat{b}$. It should be observed that contributions of k_g and k_b to $\hat{r}$ come from L as well as from G and B, but that these contributions cancel. Thus, the only increase in the
30   rms error of $\hat{r}$ is the expected contribution from the film noise in the red layer. The same result holds for the case of noise which is additive in density space, and it also holds for linear combinations of red, green and blue signals. That is,

35

green, and blue signals. The actual magnitude of the reduction depends on the relative noise levels in the different sensors and on the details of the relationship between the luminance signal and the three
5   color signals. (In the exemplary, but realistic case, a reduction of green measurement noise by 20-30% can be obtained.) If the graininess of the film is included in the noise considerations, the proportional reduction in noise will be smaller, but there are no
10 contributions to noise in one channel due to film noise in another.

    While I have shown and described an embodiment in accordance with the present invention, it is to be understood that the same is not limited
15 thereto but is susceptible to numerous changes and modifications as known to a person skilled in the art, and I therefore do not wish to be limited to the details shown and described herein but intend to cover all such changes and modifications as are obvious to
20 one of ordinary skill in the Art.

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2.   A method according to claim 1, wherein step (b) comprises generating said second signal as the difference between said first signal and said further sensor output signal.

5

3.   A method according to claim 2, wherein step (c) comprises subtracting a fraction of said second signal from each of said first sensor output signals to thereby obtain said noise-reduced estimates 10 of the information components of each of said first sensor output signals.

4.   A method according to claim 1, wherein step (c) includes generating a plurality of third 15 signals representative of the noise variances associated with the operation of said first image sensors and said further image sensor, and combining the first sensor output signals produced by said first image sensors with the second signal generated in step 20 (b) and said plurality of third signals, to thereby obtain said noise-reduced estimates of the information components of each of said first sensor output signals.

5.   A method according to claim 4, wherein a 25 respective one of said third signals is representative of the ratio of the noise variance associated with the operation of a respective first image sensor to a summation of the noise variances associated with the operation of said plurality of first image sensors and 30 said further image sensor.

6.   A method according to claim 1, wherein said plurality of first image sensors produce first sensor output signals associated with respectively 35 different color components of an image, and wherein step (a) comprises generating said first signal as a

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operation of said plurality of first image sensors and
said further image sensor, and combining the first
sensor output signals R, G and B produced by said first
image sensors with the second signal S2 generated in
5   step (b) and said plurality of third signals, to
thereby obtain said noise-reduced estimates of the
information components of each of said first sensor
output signals.

10   11. A method according to claim 10, wherein
a respective third signal, associated with one of said
color components, is proportional to a product of a
corresponding one of said coefficients and the ratio of
the noise variance associated with the operation of a
15   respective first image sensor to a summation of the
noise variances associated with the operation of said
plurality of first image sensors and said further image
sensor.

20   12. For use with a multiple band image
sensor system having a plurality of first image
sensors, each of which produces a respective first
sensor output signal that contains an information
component representative of a respective characteristic
25   of said image and a noise component associated with the
operation of the sensor through which its output signal
is produced, and a further image sensor that produces a
further sensor output signal containing an information
component that is representative of a further
30   characteristic of said image, and is expressible as a
function of the information components of said first
sensor output signals, and a noise component associated
with the operation of said further image sensor, a
method of processing said first and further sensor
35   output signals to reduce the noise components in said
first sensor output signals and thereby derive noise-

15. A method according to claim 14, wherein
said further image sensor produces said further sensor
output signal in accordance with a luminance component
of said image, and wherein step (c) comprises
5   generating a third signal as the difference between
said first signal and said luminance component
representative further sensor output signal and
subtracting from said first sensor output signals
respective combinations of said second and third
10 signals.

16. A method according to claim 15, wherein
said plurality of first image sensors produce first
sensor output signals R, G and B, respectively
15 associated with red, green and blue color components of
an image, and wherein step (a) comprises generating a
first signal S1 as a linear function of the respective
red, green and blue color representative first sensor
output signals, in accordance with the relationship:
20   S1 = aR + bG + cB,
where a, b, and c are prescribed coefficients.

17. A method according to claim 16, wherein
said further image sensor produces a further sensor
25 output signal L in accordance with a luminance
component of said image, and wherein step (c) comprises
generating a third signal as the difference between
said first signal S1 and said luminance component
representative further sensor output signal L.
30
18. A method according to claim 17, wherein
step (c) includes generating a plurality of second
signals, a respective one of which is representative of
the ratio of the noise variance associated with the
35 operation of a respective first image sensor to a
summation of the noise variances associated with the

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(a)   generating a first signal,
representative of said further image sensor signal, as
a function of said first sensor output signals;

(b)   generating a second signal
5   representative of a prescribed relationship between
said first signal and said further sensor output
signal; and

(c)   combining the first sensor output
signals produced by said first image sensors with said
10   second signal generated in step (b), to obtain said
noise-reduced estimates of the color components of each
of said first sensor output signals.

21.   A method according to claim 20, wherein
15   step (b) comprises generating said second signal as the
difference between said first signal and said further
sensor output signal, and wherein step (c) comprises
subtracting a fraction of said second signal from each
of said first sensor output signals to thereby obtain
20   said noise-reduced estimates of the color components of
each of said first sensor output signals.

22.   A method according to claim 20, wherein
step (c) includes generating a plurality of third
25   signals representative of the noise variances
associated with the operation of said first image
sensors and said further image sensor, and combining
the first sensor output signals produced by said first
image sensors with the second signal generated in step
30   (b) and said plurality of third signals, to thereby
obtain said noise-reduced estimates of the color
components of each of said first sensor output signals.

23.   A method according to claim 22, wherein
35   a respective one of said third signals is
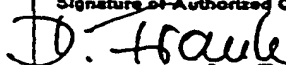representative of the ratio of the noise variance

sensor output signals R, G and B produced by said first
image sensors with the second signal S2 generated in
step (b) and said plurality of third signals, to
thereby obtain said noise-reduced estimates of the
5   color components of each of said first sensor output
signals.

27.   A method according to claim 26, wherein
a respective third signal, associated with one of said
10 color components, is proportional to a product of a
corresponding one of said coefficients and the ratio of
the noise variance associated with the operation of a
respective first image sensor to a summation of the
noise variances associated with the operation of said
15 plurality of first image sensors and said further image
sensor.

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) °

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC⁵: H 04 N 5/217, H 04 N 9/04, H 04 N 1/46

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷

Classification System	Classification Symbols
IPC⁵	H 04 N 5/00, H 04 N 9/00, H 04 L 25/00, H 04 N 1/00

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched ⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹

Category °	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	GB, A, 2191061 (ROBERT BOSCH GmbH) 2 December 1987 see the whole document	1,12,20
A	B. Widrow et al.: "Adaptive Signal Processing", 1985, Prentice-Hall, (Englewood Cliffs, US), chapters 5 and 12 see pages 71-75,302-329; figures 12.13	1-3,12,20-22,24
A	IEEE Transactions on Electron Devices, vol. ED-32, no. 8, August 1985, IEEE, (New York, US), W.C. McColgin et al.: "Analysis and measurement of pattern noise in color-filter arrays for image sensors", pages 1411-1416 see the whole article	1,4,5,12,13,20,22,23
P,A	EP, A, 0368614 (CANON K.K.) 16 May 1990 see the whole document	1,2,6,8,12,20,24,25

* Special categories of cited documents: ¹⁴

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
23rd April 1991	3 1. 05. 91

International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	D. Frank Mme Dagmar FRANK

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